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Experimental Study on Task Space Control during Physical Human Robot Interaction

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***Abstract*—In this paper new approaches for task space control during null space compliance control of a kinematically redundant robot are studied. The approaches are useful for the case where the robot experiences an external interaction on its body, especially in the human environments. The proposed algorithms guarantee safe reaction of the robot during intentional or accidental interaction by exploiting robot's redundancy through null space impedance control. The algorithms do not require joint torque measurements. The performances of the proposed controllers are verified through a variety of experiments on 7R KUKA lightweight robot arm.**

***Index Terms*—Task space control, Human Robot Interaction, Interaction Observer, Null space impedance.**

I. Introduction

THE emerging application of the robots in anthropic environments is growing rapidly. When a robot is supposed to be employed near human, it must be designed with high degree of compliance to ensure safety of any interaction. This compliance is useful for the applications including physical Human-Robot Interaction (pHRI) [1], such as service and medical robotics. In these applications, not only unexpected impacts of robot with humans are likely to happen, but also intentional physical interaction with robot maybe required. To this end, different strategies are possible. The safest approach is to avoid any unwanted Collision. However, it is usually based on exteroceptive sensors such as camera which makes it inappropriate during fast interaction. On the other hand, it is possible to cover the manipulator with a sensitive skin capable of measuring the interaction forces. Alternatively, these forces can be estimated from joint positions or torques by means of suitable observers for fast collision detection and reaction algorithms [2]. In any case the robot compliance must be increased. Compliance can be introduced passively by using elastic decoupling between the actuator and the driven link (variable joint stiffness), or actively by relying on fast control loops [3], [4]. Note that, correct execution of the operational task during interaction is also appealing and important.

Impedance control represents a very suitable framework for controlling robots in contact with an unknown environment. The problem of impedance control has been extensively studied in the literature. The compliant behavior usually is given to the operational task to control the interaction of the end-effector [5], [6]. However, the impedance behavior can be also imposed in the joint space to ensure safe interaction [7]–[9].

Kinematic redundancy has been always one of the interesting topics for robotics community. One approach to deal with the redundant degrees is multi-priority control, that is a well-established framework [10]–[12]. With this formulation for instance it is possible to control the behavior of several interaction points on the body of the robot, if the contact points are known a priori. Null space impedance as a result of multi-priority control in acceleration level was presented in [10] and [11] . The approach is motivated by the need of having control over the interaction of the robot body with the environment in the joint space in spite of the task space control. It was shown that, in order to ensure impedance behavior as the secondary task without affecting the main task, the external forces acting on the main task variables must be suitably compensated by the controller. This is possible, e.g., if the external torques are measured or estimated [7], [13]. Notice that the correct execution of the robot's main task during the interaction, subordinated to safety, is also appealing and important.

In [14] a method was presented that enables fast collision detection and safe reaction based on generalized momentum of the robot, without using any torque sensor. Also the redundancy of the robot was exploited to preserve as much as possible the execution of the end-effector task by projecting the reaction torques into the null-space of the main task [15].

In this paper the problem of controlling a robot manipulator in the task space beside a compliant behavior for the redundant degrees of freedom in the joint space is considered. An example of application scenario is depicted in Fig. 1, where a robot working on a table experiences a contact with a human. The goal is to minimize the induced main task error beside safe interaction through active compliance in the null space of the main task. To this purpose, two control approaches which do not require direct joint torque measurements was proposed in [16], [17] by the authors. The first approach is based on a disturbance observer which estimates the external forces acting on the main task variables on the basis of the task space error. The second approach relies on the momentum of the system. In both cases, the overall stability of the system, with asymptotic convergence of the main task and a desired impedance behavior in the null space of the main task, was proven through a rigorous analysis. In the following, the formulation of momentum-based interaction observer is reintroduced and

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